Chapter 1

Introduction

In this thesis, two topics are presented. The first research includes using microelectromechanical system (MEMS) technology to accomplish a flexible dual-band membrane parylene antenna and a 3D compact micromachining antenna. These fabrication and integration properties make it very advantageous and convenient in some radio frequency circuits and components, such as antenna, switch, balun and filter…etc. The second research of this thesis is the study of suppression of the LWA reflected wave and 2-directional beam-scanning features of the antenna arrays. This research includes the topics of the advantage of suppressing the back-lobe due to the reflected wave in the short LWA but also producing two separate linearly scanned beams, each of them radiating in a different region of space.

1-1. Motivation and Review of MEMS Antennas

With the increasing demand of the wireless communication system, compact and highly integrated Radio Frequency (RF) front-end is essential. In these years, many researchers employed Microelectromechanical Systems (MEMS) technology in the RF field, including devices, circuits and packaging [1], such a technology had also been referred to RF MEMS technology. By using RF MEMS technology, the compact, low cost and high performance system can be achieved. Figure 1-1 shows the system-level schematic detail of the front-end design for a typical wireless transceiver

[1]. As implied in Fig. 1-1, several of the constituent components can already be miniaturized using integrated circuit transistor technologies. Unfortunately, placing all of these components onto a single chip does very little on size reduction and performance enhancement. In order to enhance the performance and integration ability of the wireless front-end circuit, lots of components, such as switches, filters, resonators, tunable capacitors and inductors, targeted for replacement via micromechanical versions are indicated. By using RF MEMS technology, high performance System-on-Chip (SoC) or System-in-package (SiP) wireless system can be possibly achieved [2].

Though lots of efforts had been paid on the development and applications of RF MEMS technology, one can find that just a few researches focused their attentions on the RF MEMS antenna [3]. In order to produce a complete wireless front-end system, the implementation of a low cost, small volume and high performance antenna needs to be further studied. Taking the advantages of RF MEMS technology, the antenna with required performance and characteristics for RF front end module can be achieved. As the higher frequency communication systems are developing, such as local multipoint distribution systems (LMDSs) and WLANs operated at around 60 GHz, the performance and size requirements of the antenna are demanding. Not only the fabrication tolerance of the antenna become tighter than before due to its smaller size, but also antenna of lower cost are needed for personal communication systems.

Micromachining technology offers tremendous potential for satisfying these requirements due to its precise fabrication technique, batch production and the potential ability of integration with integrated circuits (ICs). Several kinds of antenna had been fabricated with micromachining technology in recent years, and are reviewed in the followings.

(1) Trenches or cavities can be formed in the substrate directly located under the antenna by micromachining technique to lower the effective dielectric constant of the substrate and hence lower the surface wave and substrate loss, therefore improving the radiation efficiency of the antenna. The researcher had removed almost all of substrate below the antenna patch by back side etching, as shown in Fig. 1-2 [4]. This approach has achieved about 60% improvement in bandwidth of the antenna, and also improved its radiation efficiency, Q. Chen et al had fabricated micromachined trenches below the radiating edges of the antenna, as shown in Fig. 1-3 [5], they reported about 40% improvement in bandwidth and a remarkable improvement in radiation efficiency were achieved. Similar approaches were also used in the same way to improvement the radiation efficiency of the antenna and reduce the mutual coupling between the antennas [6].

(2) Micromachining technique can also be used to construct a 3-dimensional antenna. Shenouda et al bonded two separated silicon substrates with V-grooves built on them to form the horn antenna for W-band application, as shown in Fig. 1-4 [7]. Similar work had been also reported by S.G. Gearhart et al, in their paper, a tapered slot antenna was fabricated by LIGA micromachining [8].

(3) Antennas with the ability of adaptively changing their characteristics are called reconfigurable antennas. Reconfigurable antennas are primarily used as satellite broadcast antennas. Micromachining technology also can be used in the design and fabrication of reconfigurable antennas. D. Chauvel et al reported a micro strip antenna which was suspended by a pair of torsion bars, as shown in Fig. 1-5 [9]. Two electrodes on the substrate were used to control the rotation of the antenna by means of electrostatic force, and hence beam steering capabilities can be achieved. J.C. Chiao et al used the MEMS actuator to control the angles of the arms of a V-shape antenna which was operated at 17.5 GHz, as shown in Fig. 1-6 [10]. One can adjust

the angle between the arms to change the beam shape. Also, one can rotate both arms at the same time, and hence the beam directions can be altered.

(4) Reconfigurable antennas can also be realized by means of add/drop MEMS devices, such as relays, switches and varactors, built in the antenna to alter the configuration or resonance length of the antenna [11]~[13]. Sinan ONAT et al proposed a multifunctional reconfigurable antenna that can change its operating frequency and radiation/polarization characteristics. As shown in Fig. 1-7, each individual element of the array can be dynamically reconfigured in its structural geometry, henceforth referred to as multifunctional reconfigurable antennas. Thus, such a reconfigurable antenna can alter its radiation/polarization and frequency characteristics by morphing its physical structure [14]. Note that RF MEMS phase shifters can also be added in the antenna design to achieve beam steering.

This part of the dissertation describes monopole antenna designs and fabricated on flexible and glass substrates; antenna on flexible substrate has its uniqueness in special applications where flexibility is advantageous, and antenna on glass substrate should have better performance compared to that built on silicon substrate due to its lower loss property of glass.

1-2. Motivation and Review of Active Scanning LWAs

Microstrip leaky-wave antenna was famous due to its fabrication simplicity, low profile and frequency-scanning capability. Hence, it is suitable for millimeter wave applications [15]. Menzel first discovered the phenomenon of the microstrip leaky wave antenna [16]. Compared to resonant antennas, the microstrip leaky-wave antenna has the wider bandwidth. The advanced researches on its nature of the leakage from higher order mode are described by Oliner [17]. Then, Oliner and Lee clarified the confusion of properties and divided the leakage modes into two forms: the surface and the space wave. In 1996, C.K. Tzuang firstly integrated an oscillator with a microstrip leaky-wave antenna for power combining at about 8.5GHz [18].

Although the leaky wave antenna has excellent beam-scanning ability, the serious problem of the leaky-wave antenna lies in structures of huge size and long length. Besides, the reflected wave resulting from the mismatch of the open end of the microstrip LWA may confuse the main beam determination for the applications of the microwave wave satellite communication system. Hence, there has been a lot of research devoted to studying this issue with the hope to reduce the LWA length without the reflected wave in order to make the use of LWAs more extensively. In reference [17], the LWA with a short length ($2.23\lambda_0$), a width of 1.5cm on the substrate with thick 0.794mm and dielectric constant 2.2 can radiate out about 65% of the power and the remaining 35% power would be reflected due to the open end. This reflected wave produces the back lobe, whose amplitude was about 0.4 of the main beam at the same angle from broadside. However, if the strip length of the antenna is increased to $4.85\lambda_0$, then 90% power could radiate out. Figure 1-8 shows the simulated pattern of the MLWA with different length at 10GHz ($2\lambda_0$ and $4\lambda_0$).

In [19], the topology of microstrip LWA array with a single VCO source are designed to enhance gain, sharpen the main beam, and reduce the back lobe as shown in the Fig. 1-9(a). In [20], the active integrated feedback-amplifier leaky-wave antenna could reduce the back lobe. The most output power of amplifier is radiated by antenna, and the remaining power is feeding back from the taper-end port to the input port of the amplifier as shown in the Fig. 1-9(b). However, all the designs mentioned above require large circuit size or complicated structure. Furthermore, LWA had been demonstrated 2-D beam-scanning in the elevation plane (the H plane) and the cross plane (the quasi-E plane) have been made by encompassing the phase control technique of the coupling oscillators or by utilizing the 4 × 1 aperture-coupled series-fed electronically steerable microstrip LWA array [21]~[22].

In the second part of this dissertation, a two-directional linear short LWA scanning array was demonstrated with aperture-coupled patch antenna arrays on the backside. It proposes a technique not only having the advantage of suppressing the back-lobe due to the reflected wave of the short LWA, but also producing two separate linearly scanned beams in a different region of space. The two linear beam-scanning radiation patterns of individual direction can be created independently: one narrow beam in the elevation plane on the front side and one broadside beam in the cross plane on the backside.

1-3. Thesis Organization

The dissertation is organized as follows. Chapter 1 gives an introduction of this paper. Chapter 2 is devoted to the general descriptions of the microelectromechanical technology and fundamental theories of monopole and leaky-wave antenna. The description only provides up to the level sufficient to comprehend the research work carrying out in this dissertation. In Chapter 3, a MEMS dual-band monopole antenna fabricated on a parylene membrane for wireless application was designed, fabricated and characterized, as shown in Fig. 1-10. From our experimental results, the measured results of the fabricated antenna agree very well with the simulated results, and hence the characteristics of the antenna can be well designed and accurately predicted before fabrication. In Chapter 4, a compact three dimensional MEMS antenna for WLAN (802.11b) was designed, fabricated, and measured, as shown in Fig. 1-11. Measured performances of the fabricated antenna are in good agreement to the designed values in terms of operating frequency at 2.45 GHz. The same structure of this monopole antenna has also been successfully fabricated on silicon substrate. In Chapter 5, a short leaky wave antenna utilizing an aperture-fed patch antenna is presented. The proposed structure can not only suppress the reflection power but also producing 2D scanning function. In Chapter 6, conclusions and future work are made and the new ideas for further research are also suggested as a future work. A novel platform of MEMS relay, switch and phase shifter would been detailed discussed. With its simple fabrication process, the circuit integration could be realized in the future.

1-4. References

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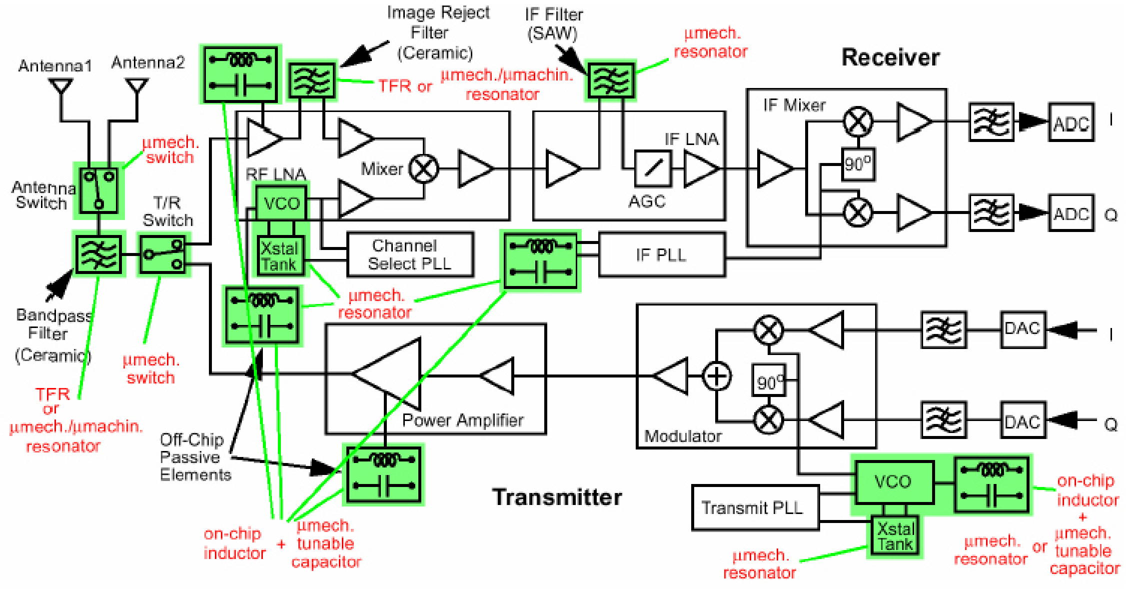


Figure 1-1: System-level schematic detail of the front-end design for a typical wireless transceiver. (1-4. [1])

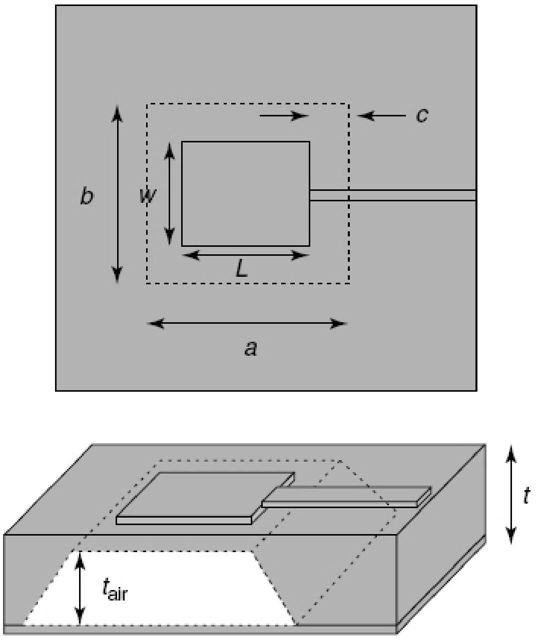


Figure 1-2: Micromachined microstrip antenna with a portion of substrate material below the patch removed by backside etching. (1-4. [4])

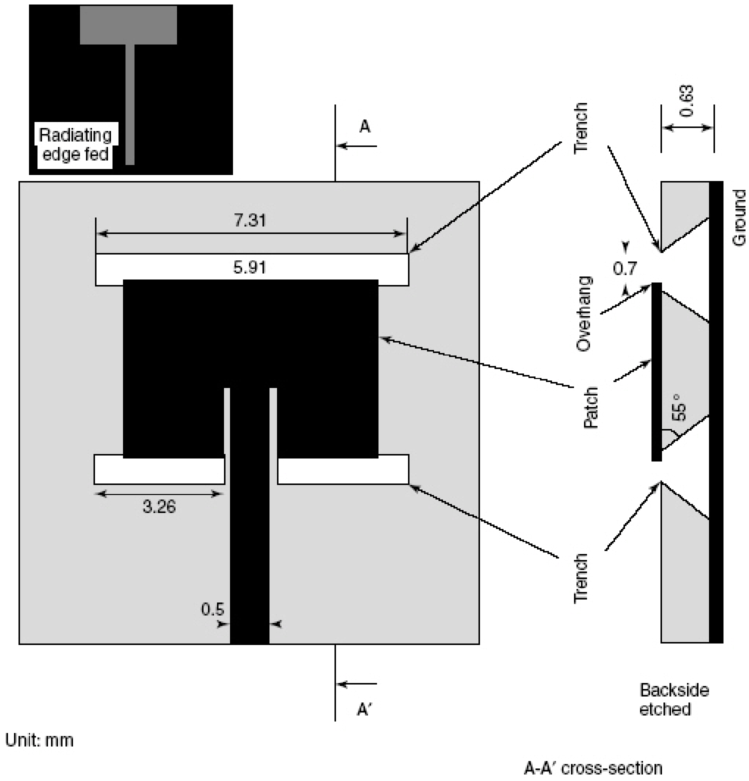


Figure 1-3: Microstrip antenna with micromachined trenches below its radiating edges. (1-4. [5])

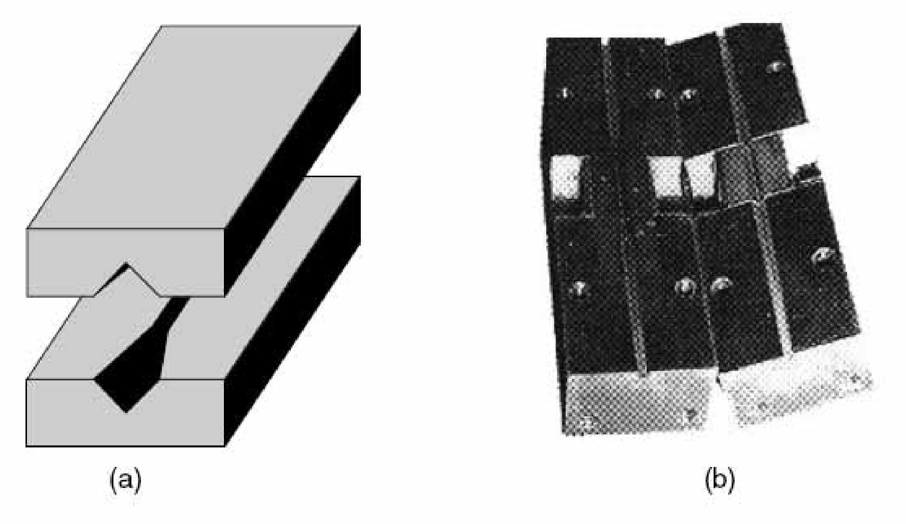


Figure 1-4: A micromachined horn antenna for W-band application: (a) schematic; (b) photograph of fabricated antenna. (1-4. [7])

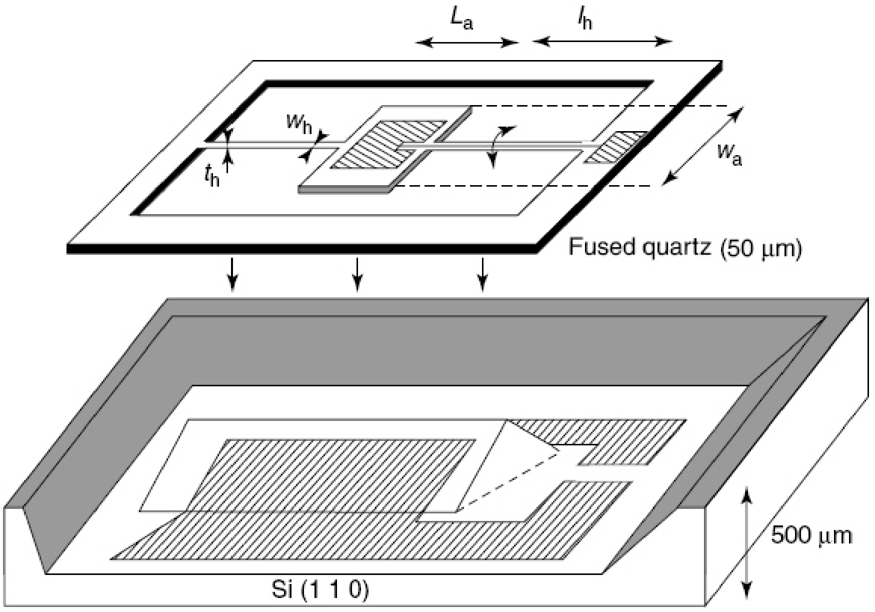
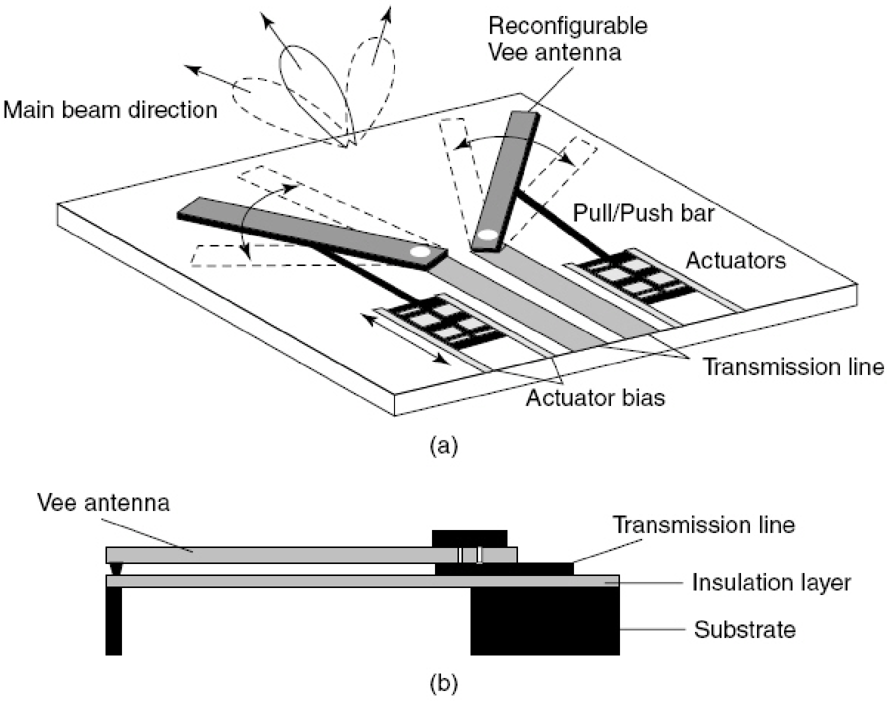


Figure 1-5: Micromachined microstrip antenna with the ability of beam steering. (1-4. [9])



(a)

(b)

Figure 1-6: Micromachined Vee antenna for both beam shaping and beam steering. (1-4. [10])

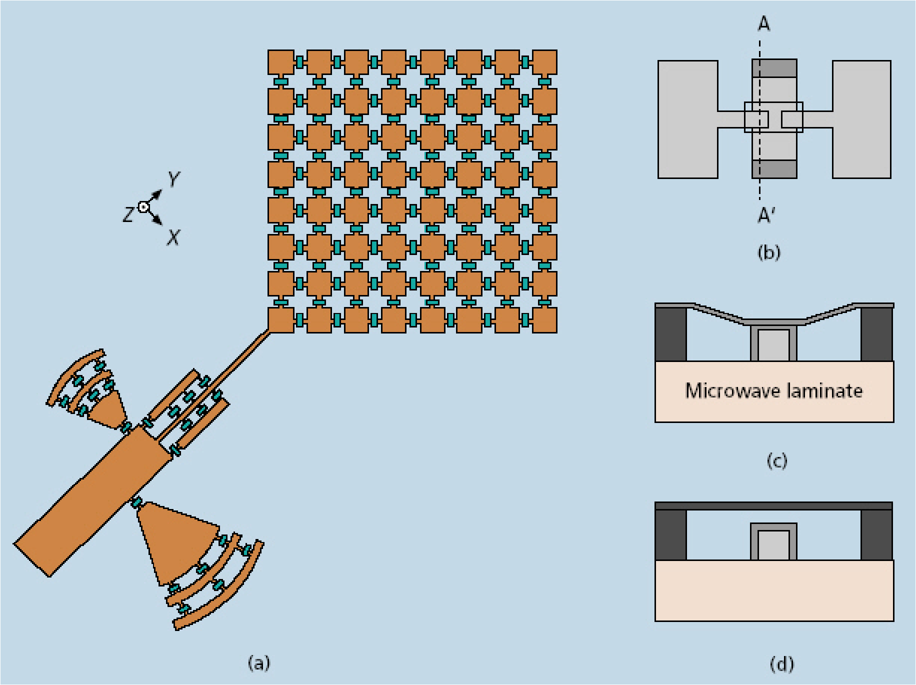


Figure 1-7: (a) Schematic of the proposed reconfigurable pixel-patch antenna architecture; RF MEMS actuator; (b) top view; (c) side view (down position); (d) side view (up position). (1-4. [11])

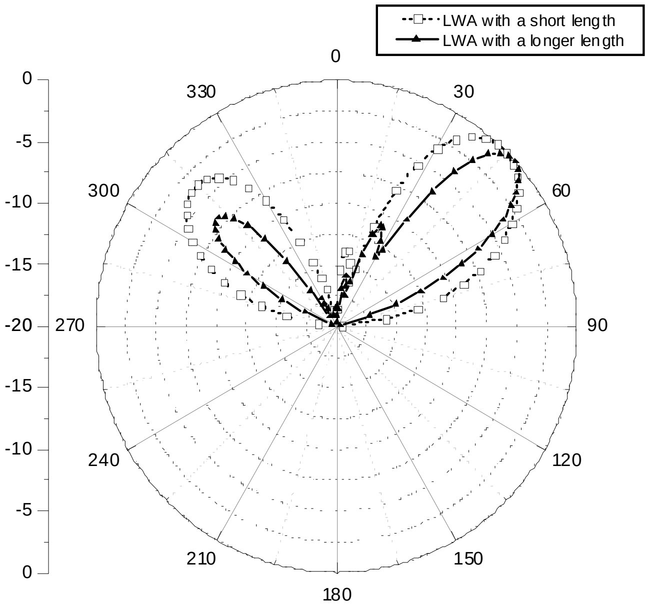
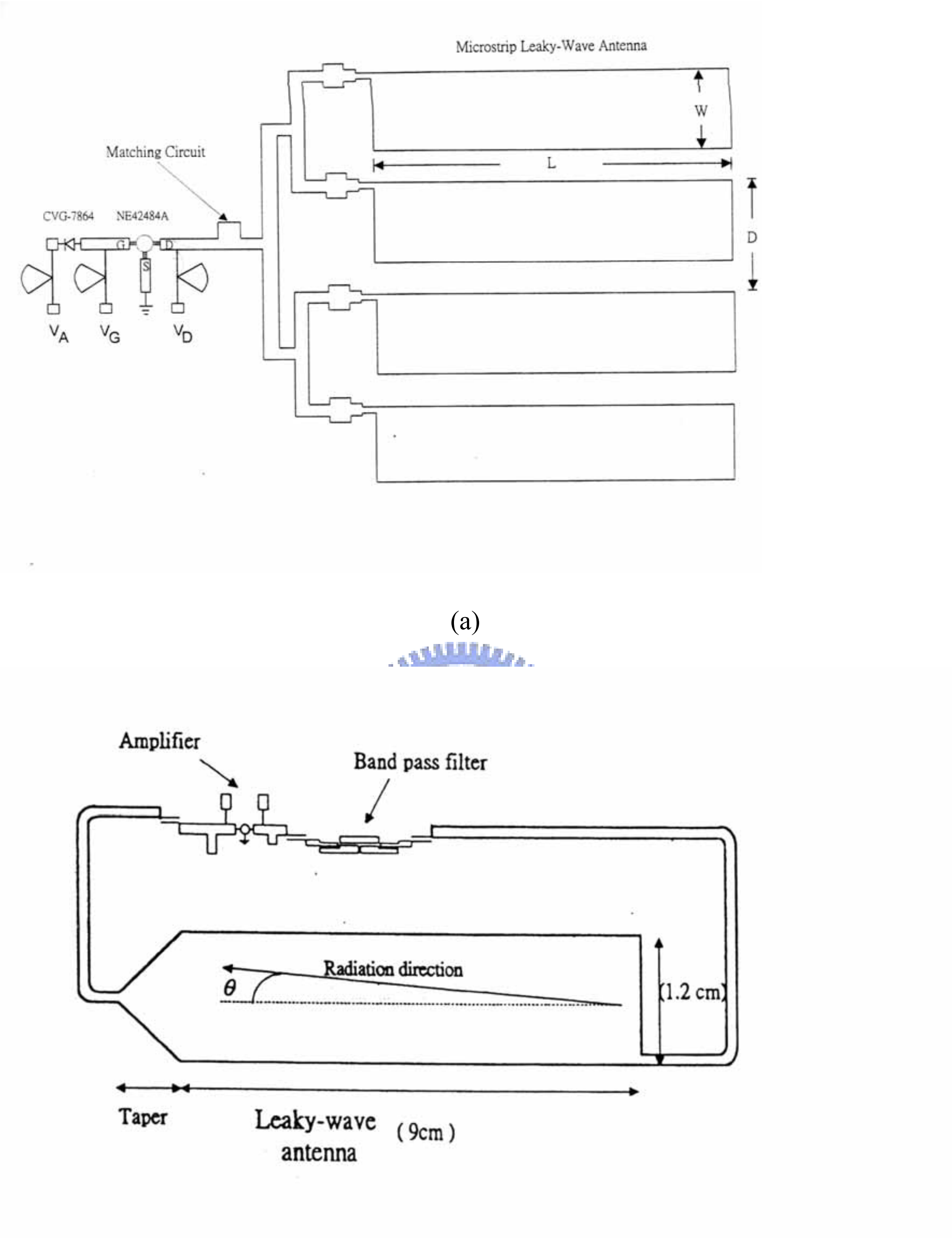


Figure 1-8: The open-end effect with different length ($2\lambda_0$, $4\lambda_0$). (1-4. [17])



(a)

(b)

Figure 1-9: (a) Array topology for the suppression of the reflected wave. (1-4. [19])

(b) Taper end and active feed back for the suppression of the reflected wave. (1-4. [20])

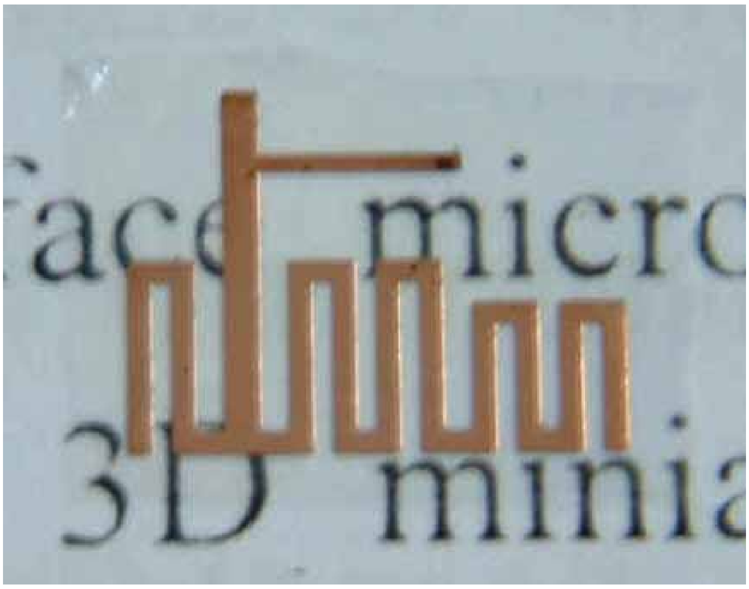


Figure 1-10: A dual-band monopole antenna fabricated on a parylene membrane.

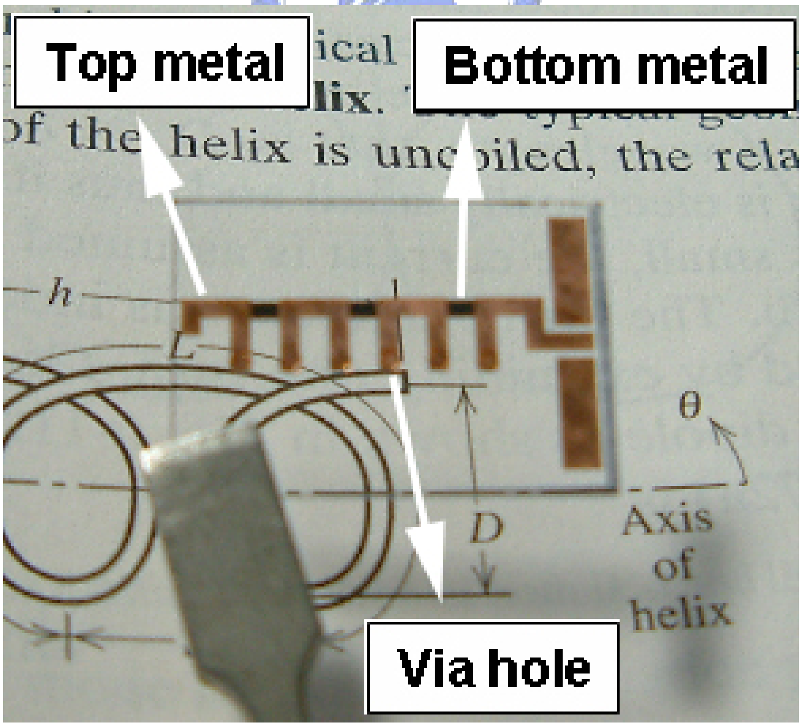


Figure 1-11: A compact three-dimensional MEMS antenna.